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Title: Fielding of the newest Gas Cherenkov Detector (GCD-3) at OMEGA

Author(s): Herrmann, Hans W.
Kim, Yong Ho
Oertel, John A.

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Fielding of the newest Gas Cherenkov Detector (GCD-3) at OMEGA

Hans W. Herrmann, Y.H. Kim, J. Oertel

& Gamma Team

9/22/14

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Super GCD Acknowledgements

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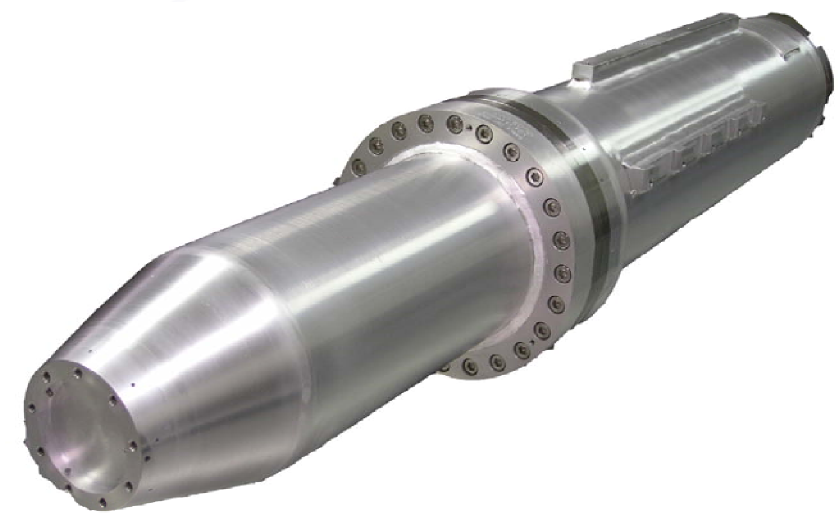
National Security Technologies LLC Vision • Service • Partnership

"Super" GCD (GCD-3 at Ω) now provides High-Sensitivity, Low-Threshold capability at OMEGA (and eventually at NIF)

"Super" GCD



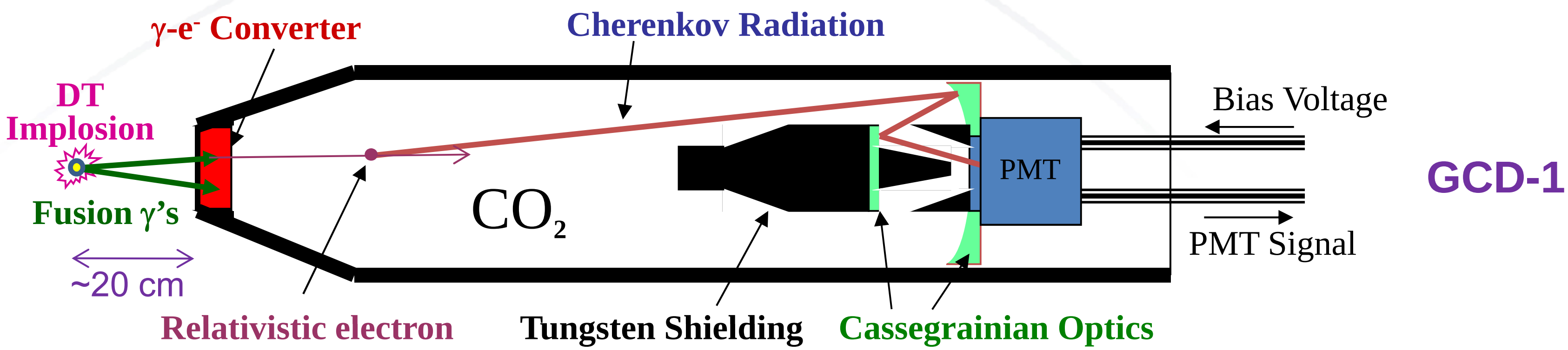
- Low Threshold, High Sensitivity
  - ~2 MeV threshold
  - 20 cm from TCC (TIM mounted)

Physics Driven Requirements:

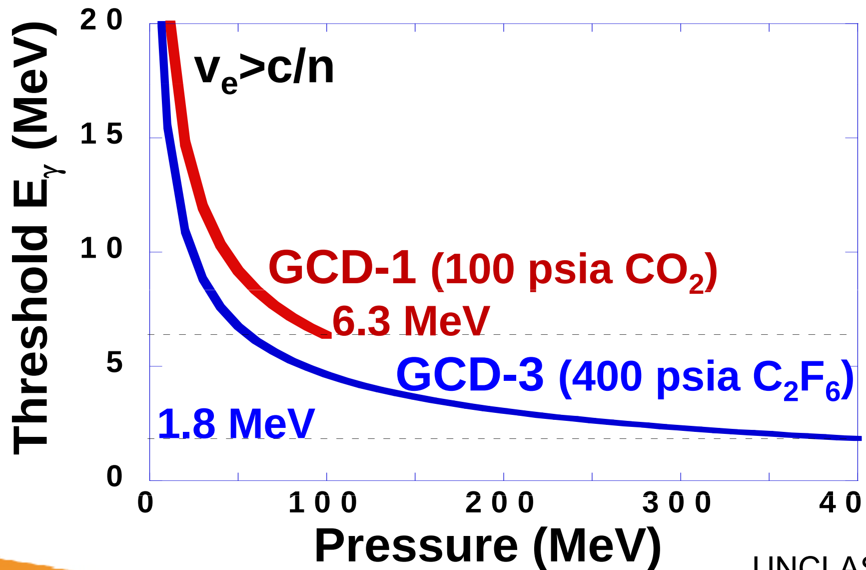
- Low Threshold (≥1.8 MeV) to reveal new portions of gamma-ray spectrum
  - High pressure (400 psia) → redesigned pressure boundary
  - Fluorinated gases → metal seals to achieve <1e-9 scc/s leak rate
- High Sensitivity
  - TIM-based to capture solid angle
  - Modular optics package to optimize SNR
- Absolute Timing & Dry Run capability
  - 2ω fidu injection *(not yet implemented)*
- Improved SNR
  - better shielding
  - additional precursor to signal delay

Gas Cherenkov Detector (GCD)

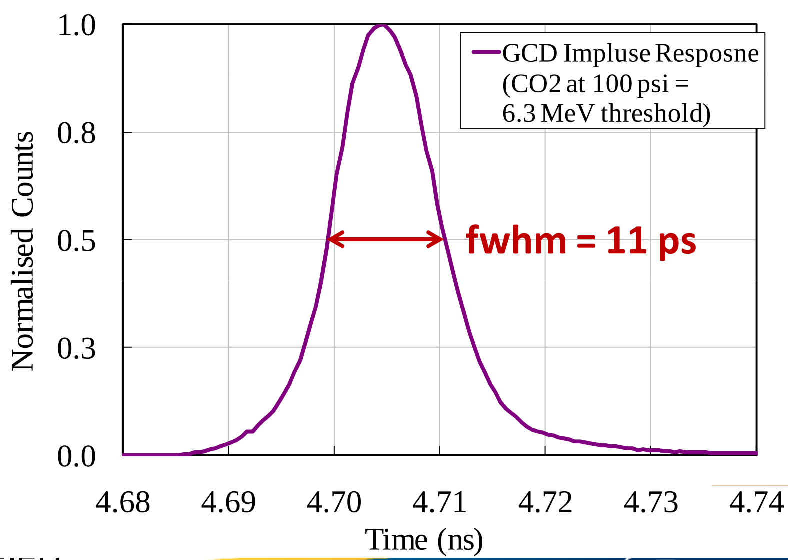
1. Convert MeV γ-rays to UV/Visible photons



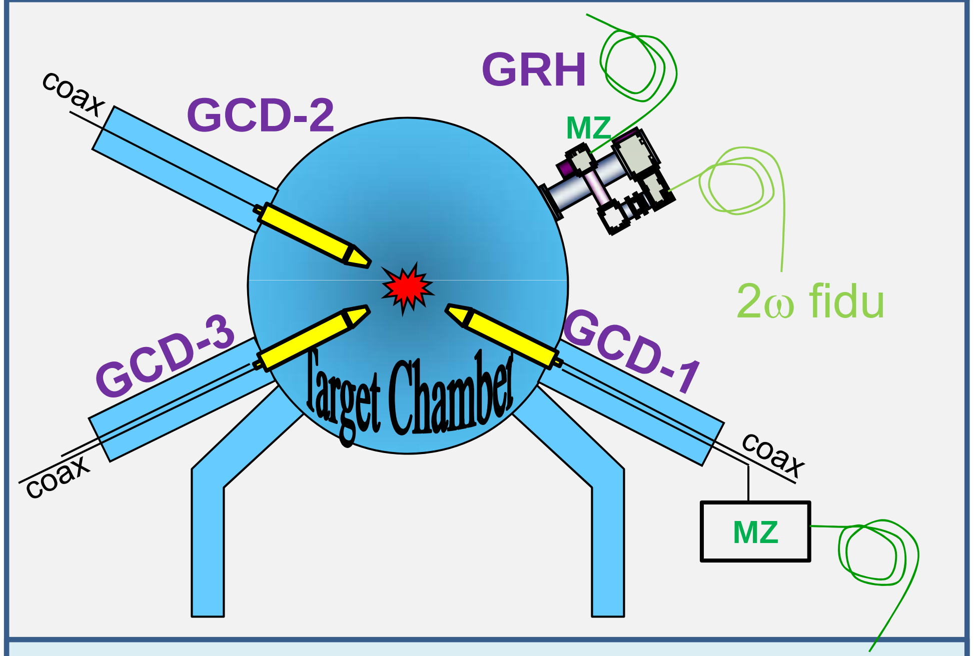
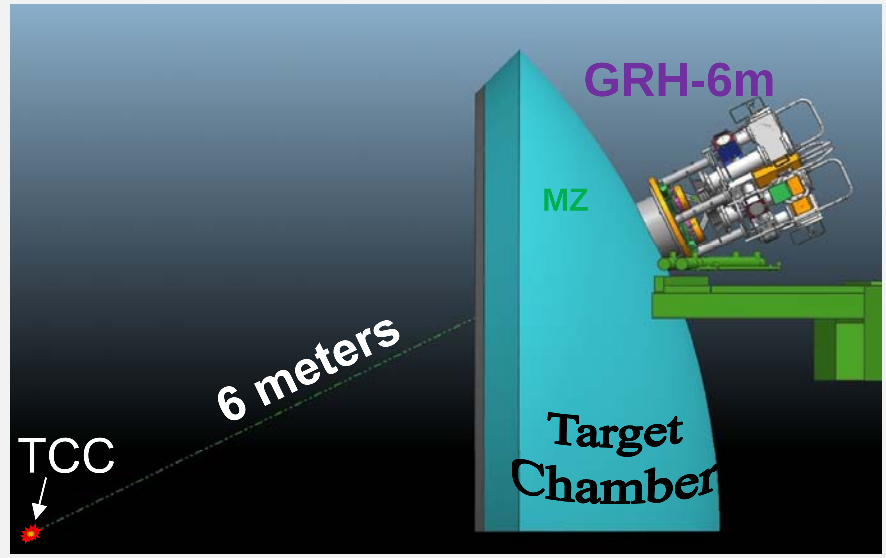
2. Variable Energy Thresholding



3. Fast Time Response

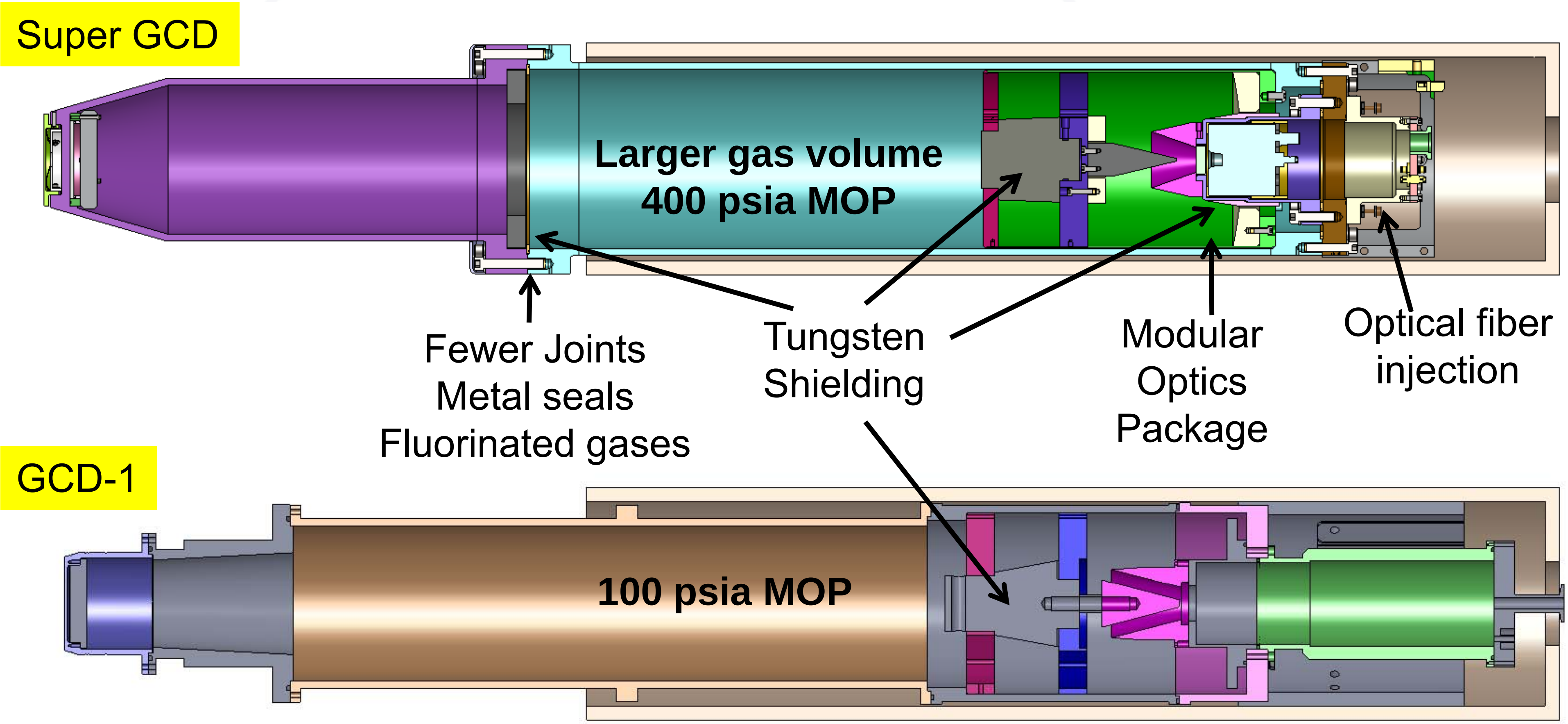


GCD-3 provides enhanced performance at OMEGA, and acts as a prototype for a NIF GCD ("Super" GCD)

OMEGA-60	NIF
	
3 GCDs (20cm), 1 GRH (187cm)	4 GRHs (607 cm)

Omega can run 3 GCDs simultaneously (+1 GRH)
Propose bringing TIM-based GCD to NIF

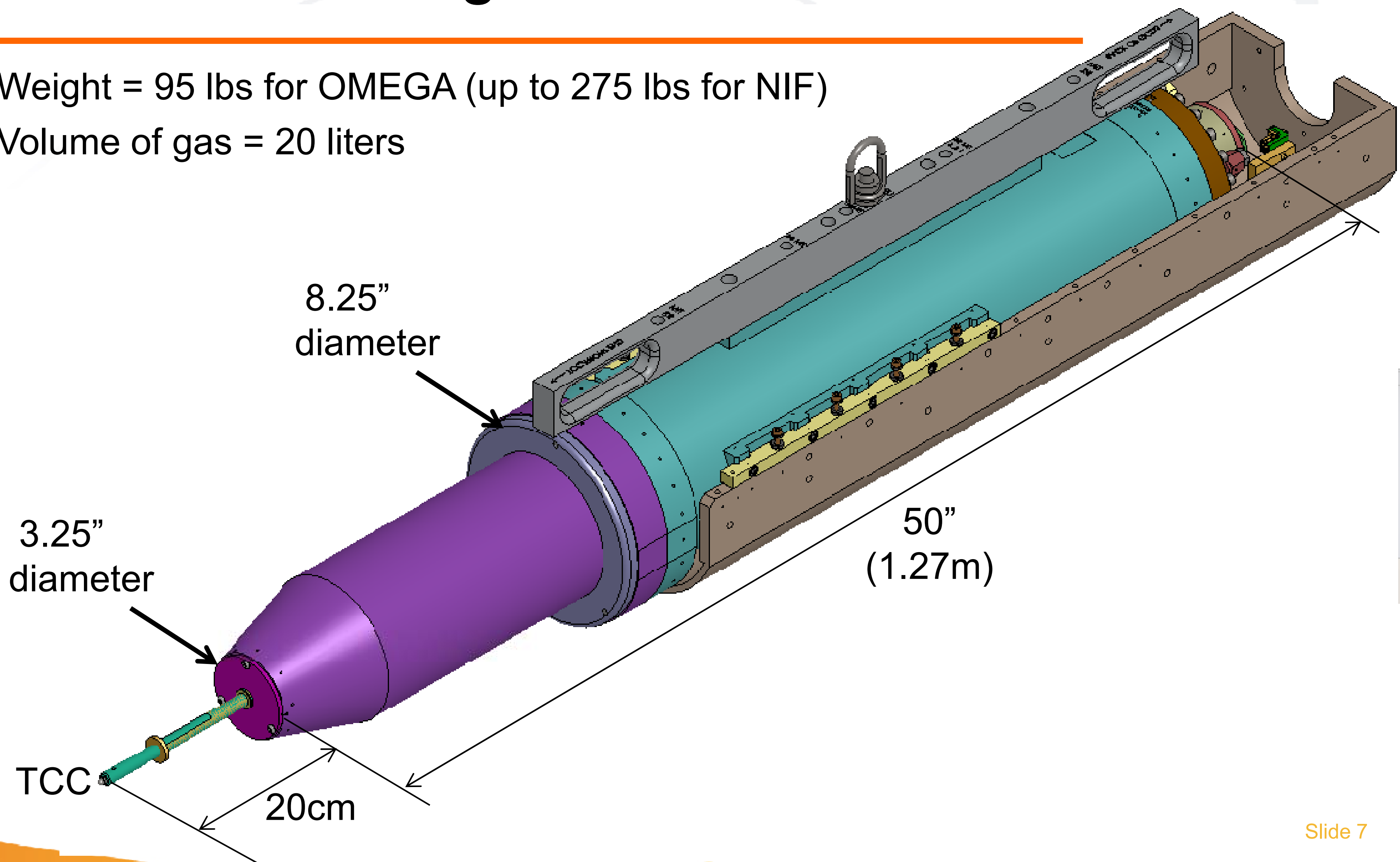
Super GCD employs significant enhancements to GCD-1



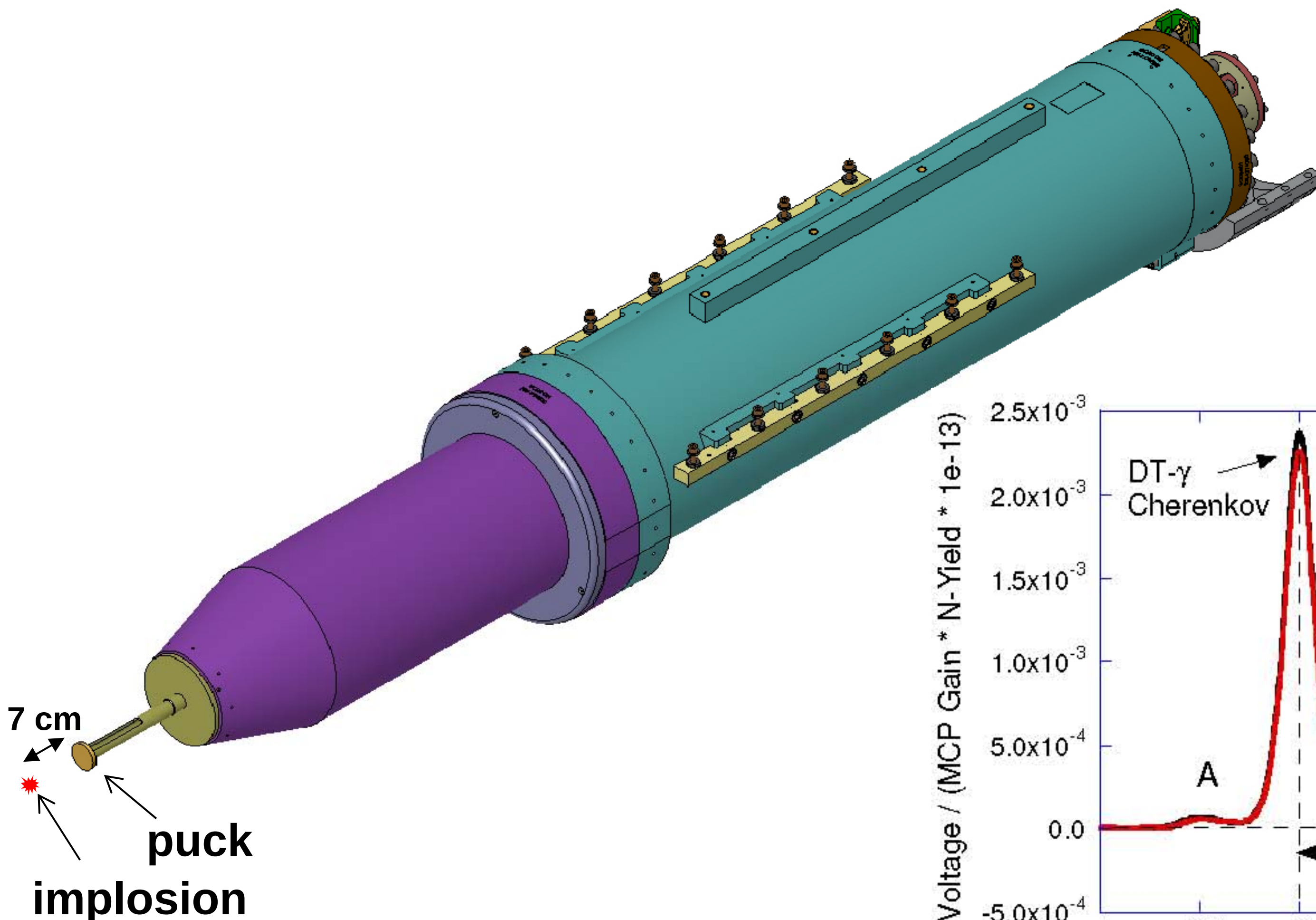
GCD-3 now being fielded on OMEGA

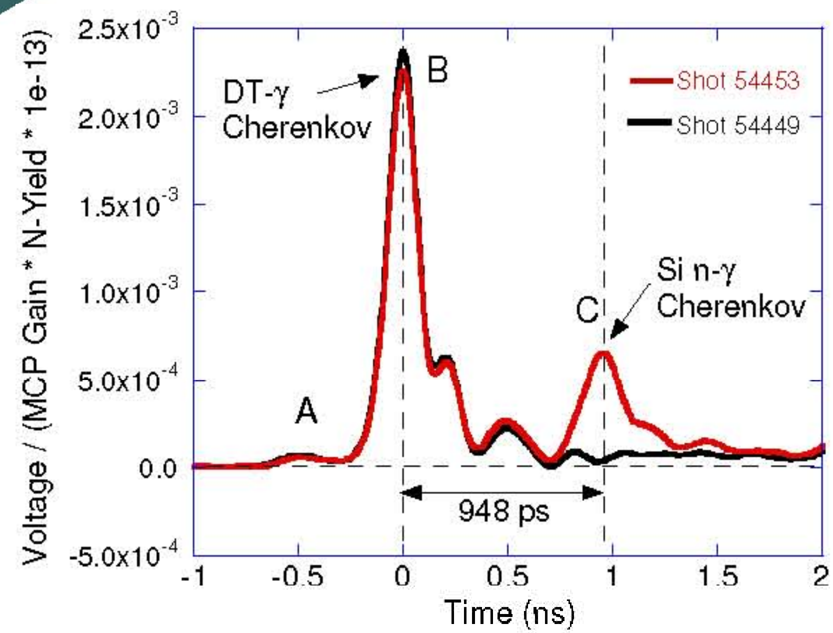
Weight = 95 lbs for OMEGA (up to 275 lbs for NIF)

Volume of gas = 20 liters



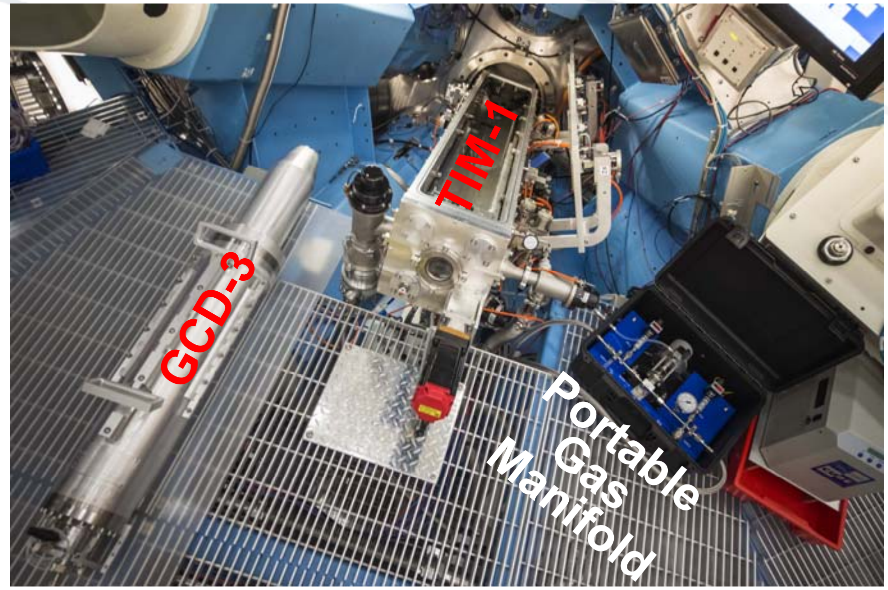
Integral puck holder allows study of 14 MeV neutron interactions with materials placed near





Y. Kim, et. al, JoP, 2010

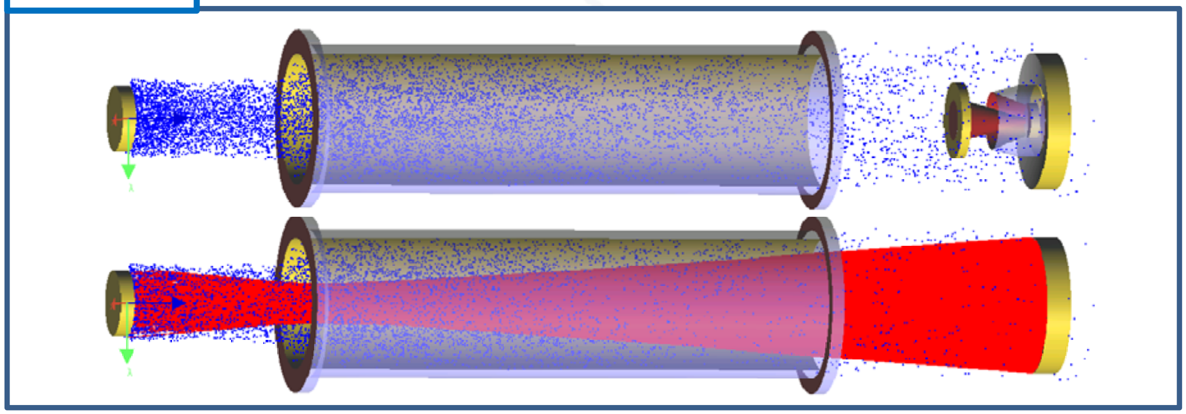
First GCD-3 use on OMEGA, July 31, 2014



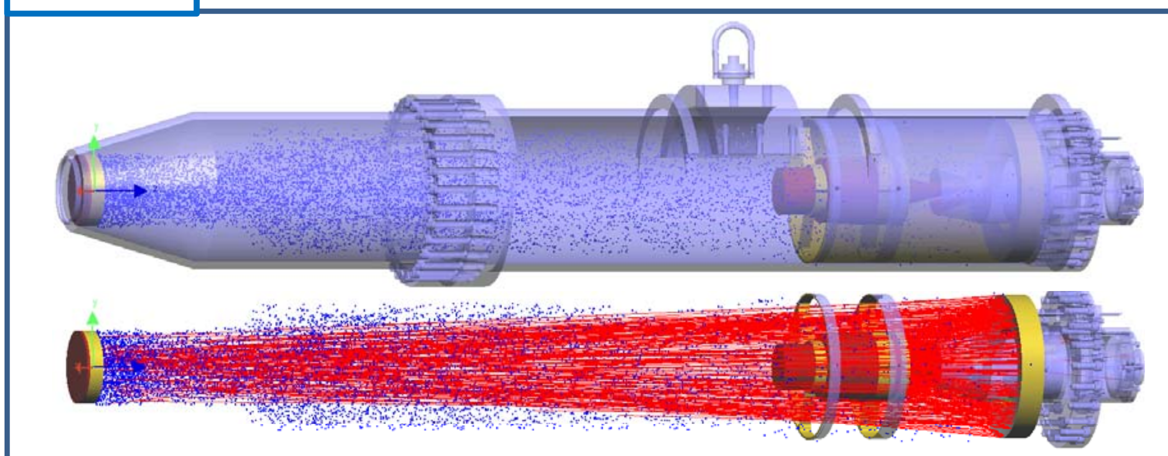
GCD-3 shielding & optics designed to improve SNR

- GEANT-4 Cherenkov simulations (5.5 MeV pD gammas at 2.7 MeV threshold)
- Optical ray tracing used to optimize light collection in GCD-3
  - Aspheric secondary mirror
- GCD-3 ~20% less efficient than GCD-1 at given pressure, but better Signal-to-Precursor separation

GCD-1

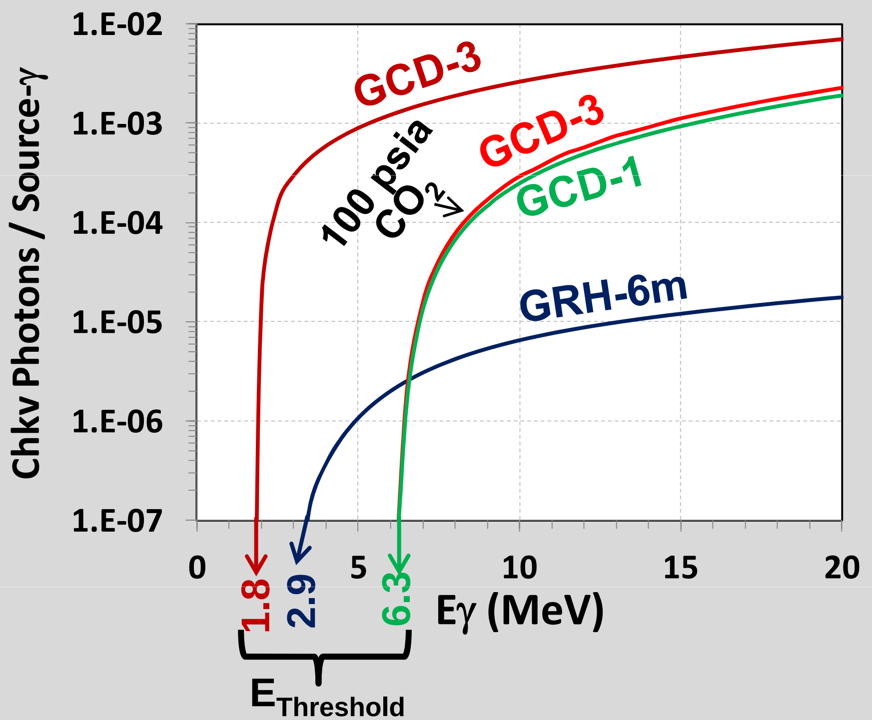


GCD-3

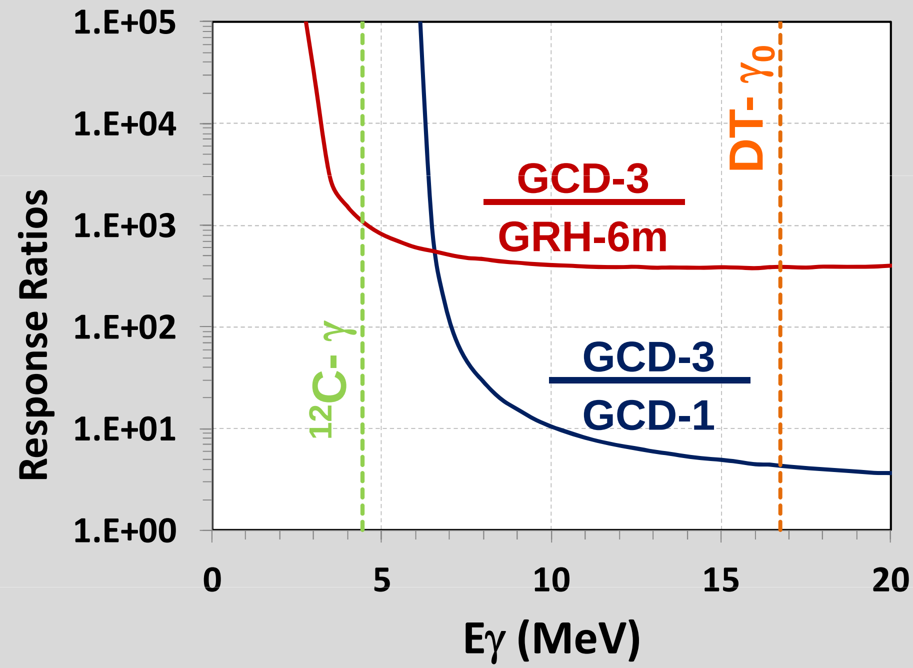


Super GCDs superior Detection Efficiency demonstrated through GEANT simulations

Detection efficiency (at given $E_{threshold}$)



Efficiency Ratios (at minimum threshold)



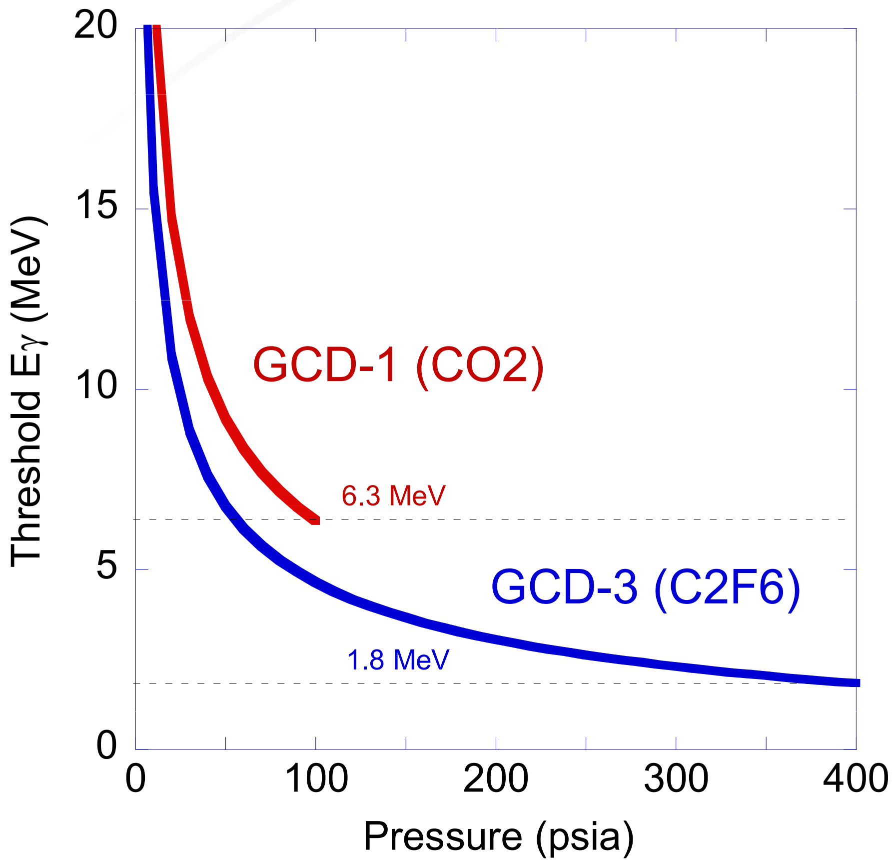
GCD-3 sensitivity comparable to GCD-1 at same pressure, but SNR improved.
GCD-3 several orders of magnitude more sensitive than GRH-6m at lowest threshold

Key Capability Improvements for GCD-3

- Low threshold (≥1.8 MeV)
  - GCD-1 limited to ≥6.3 MeV
  - GRH limited to ≥2.9 MeV

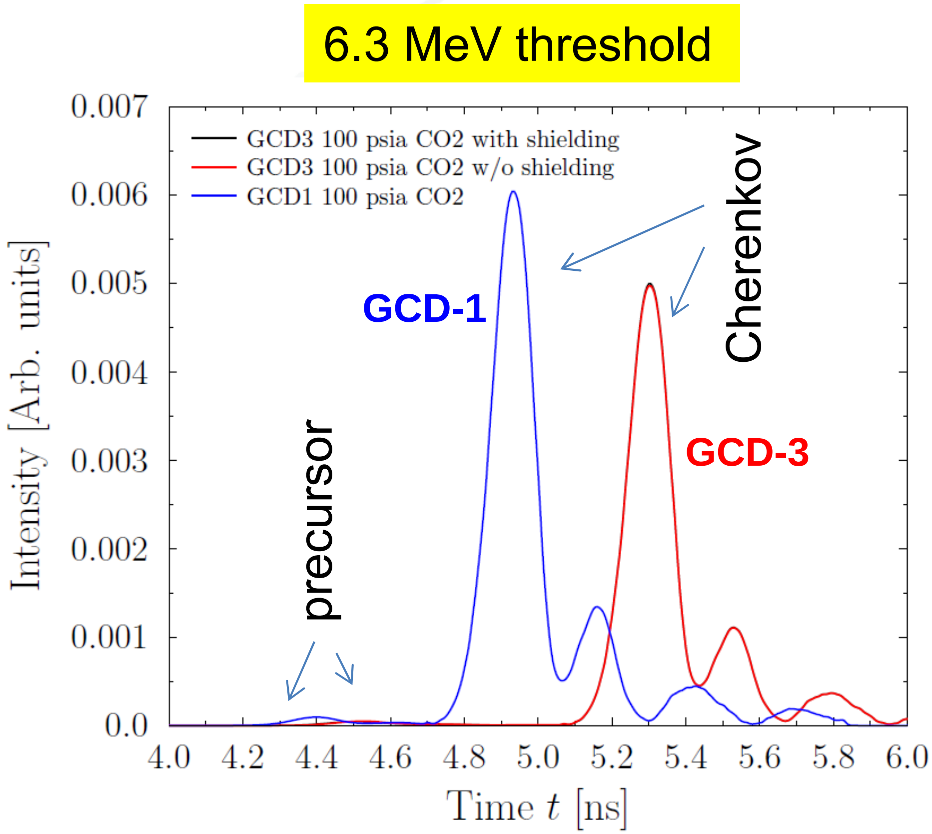
- Increased sensitivity
  - ~5x sensitivity to DTγ at lowest threshold than GCD-1
  - >20x sensitivity of GRH-$\Omega_{1.87m}$ at fixed threshold
  - >200x sensitivity of NIF GRH-6m at fixed threshold

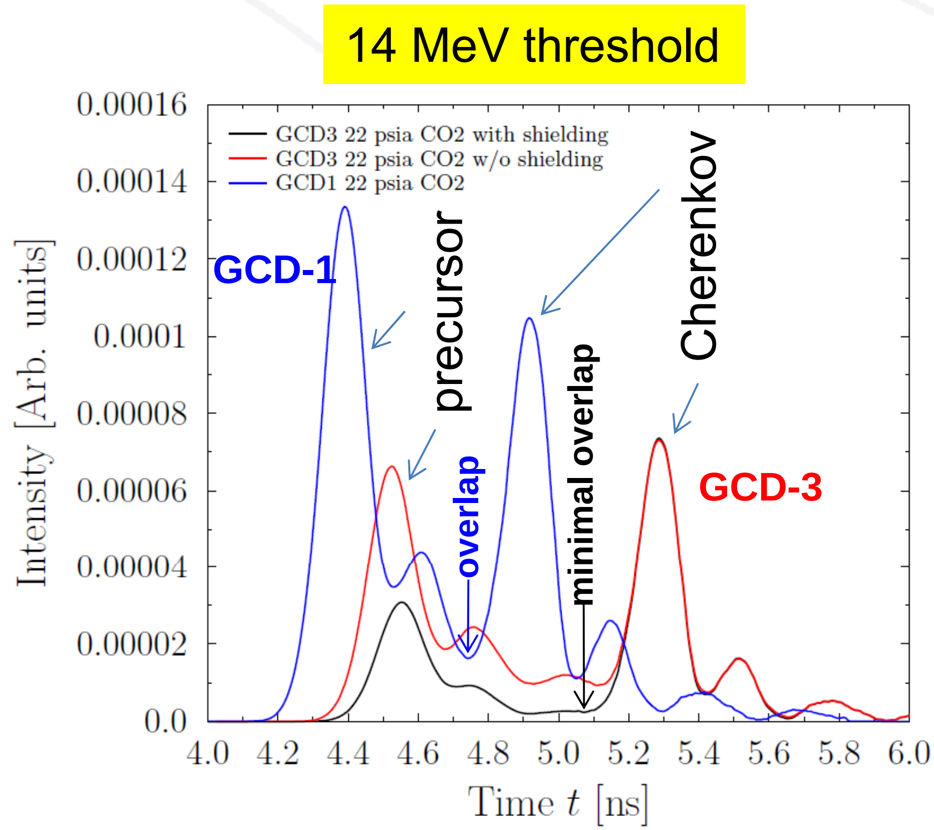
Lower Energy Threshold (~ 2 MeV) opens up new portions of gamma-ray study



- **New gamma-ray detection (too low E for GCD-1, too dim for GRH):**
  - $^{16}O(n,n'\gamma)$ at **6.1 MeV** (SiO_2 ρR)
  - $^{13}C(d_{ko},n)^{14}N^*$ at **5.69 MeV** (CH Mix)
  - $^{9}Be(\alpha,n)^{12}C^*$ at **4.44 MeV** (Be Mix)
  - $^{9}Be(d_{ko},n)^{10}B^*$ **3.4 MeV** (Be Mix)
  - $^{10}B(d_{ko},n)^{11}C^*$ at **~7 MeV** (B_4C or BH Mix)
  - HD-γ at **5.5 MeV** (MIT Zylstra PhD)

Super GCD designed to have better S/N than GCD1, particularly at high threshold





- ➢Additional ¼ ns temporal separation betw precursor and Cherenkov
- ➢Additional shielding to knock down precursor

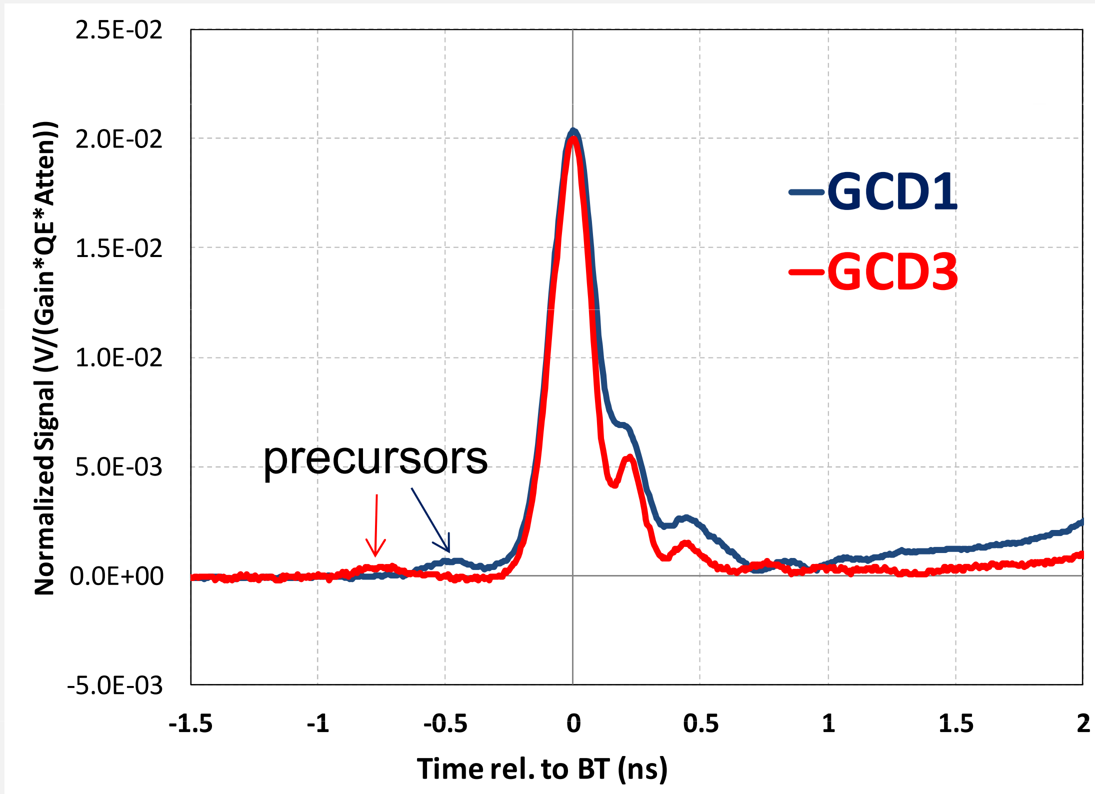
GEANT4 courtesy Mike Rubery (AWE)

Goals of first 3 Omega shot days for GCD-3

	Thurs (7/31)	Tues (8/26)	Thurs (8/28)
Campaign	NuclearAstro-14A	Neutron Imaging	StellarRates-14B
Goal	**DH 5.5MeV gamma**	CNXI at Y>1e13 DTn	**DH 5.5MeV gamma**
Capsule	DH, D_2, H_2, D^3He	DT(10)CH[15]	DH, D_2, H_2, D^3He
Gamma Goal	GCD3 with CO_2	GCD3 vs GCD1 GCD3 with C_2F_6 ^{13}C Puck vs ^{12}C puck	GCD3 with C_2F_6 GCD3 with CO_2

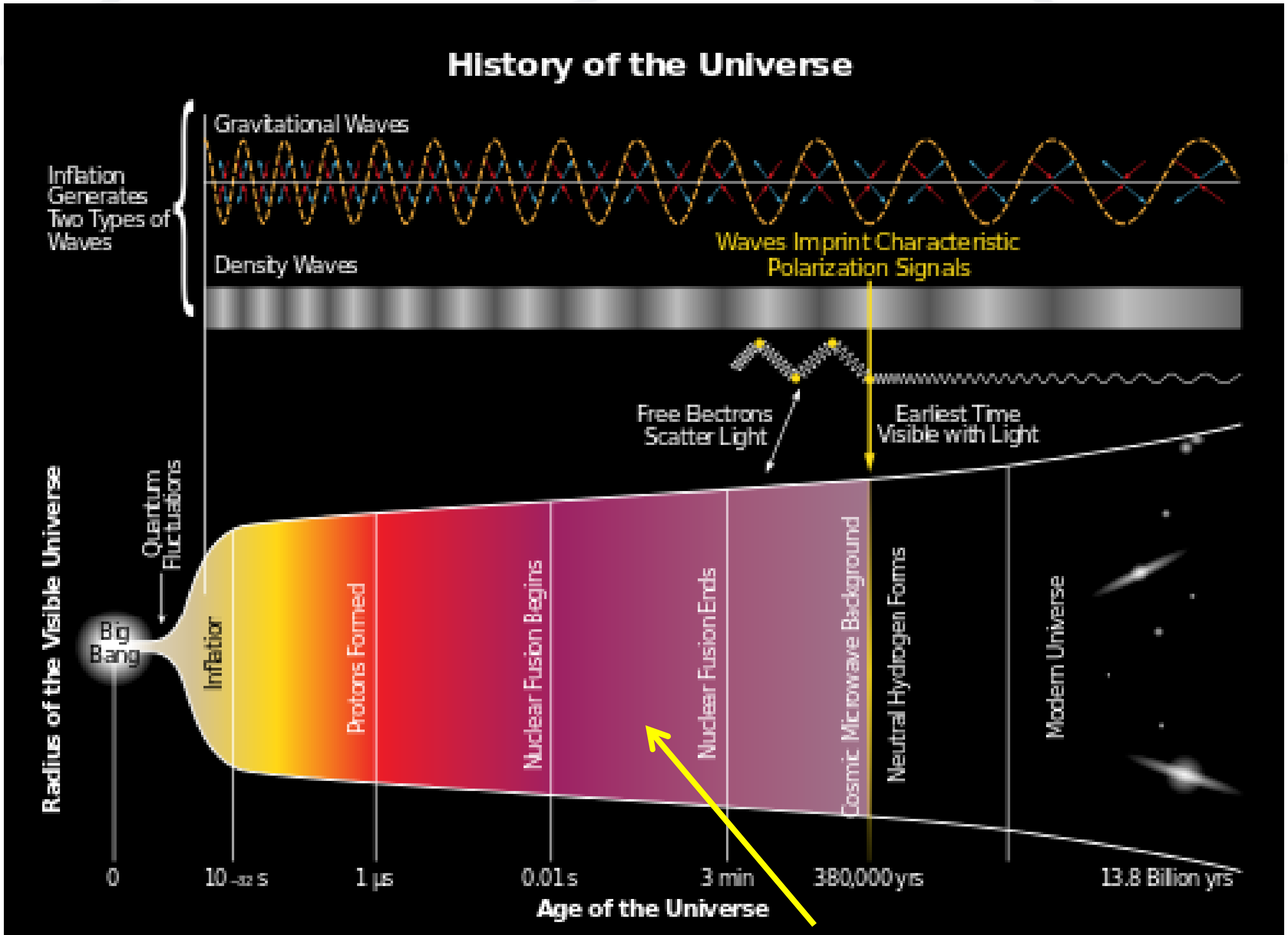
Preliminary data from Aug 26 shows GCD-3 improvements

Direct GCD-3 vs GCD-1 comparison at 100 psia CO_2



GCD-3 has earlier precursor and cleaner return to baseline (faster response due to PMT110 vs 210)

OMEGA NLUF p+D experiments
NuclearAstro-14A, July 31st 2014



BICEP2

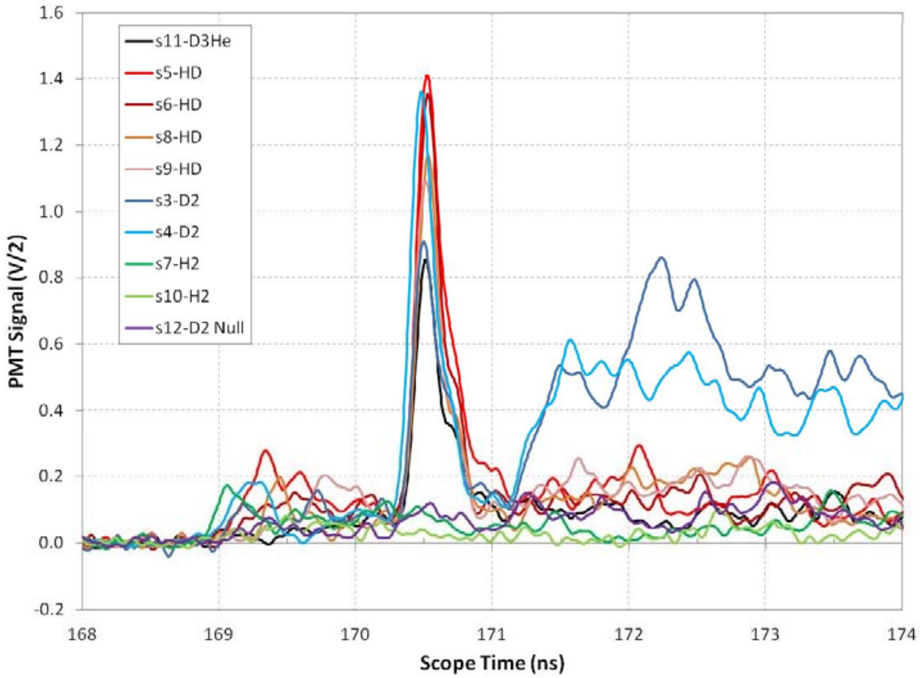
Big Bang Nucleosynthesis

p + D ➔ $^{3}He + \gamma$ (5.5 MeV)

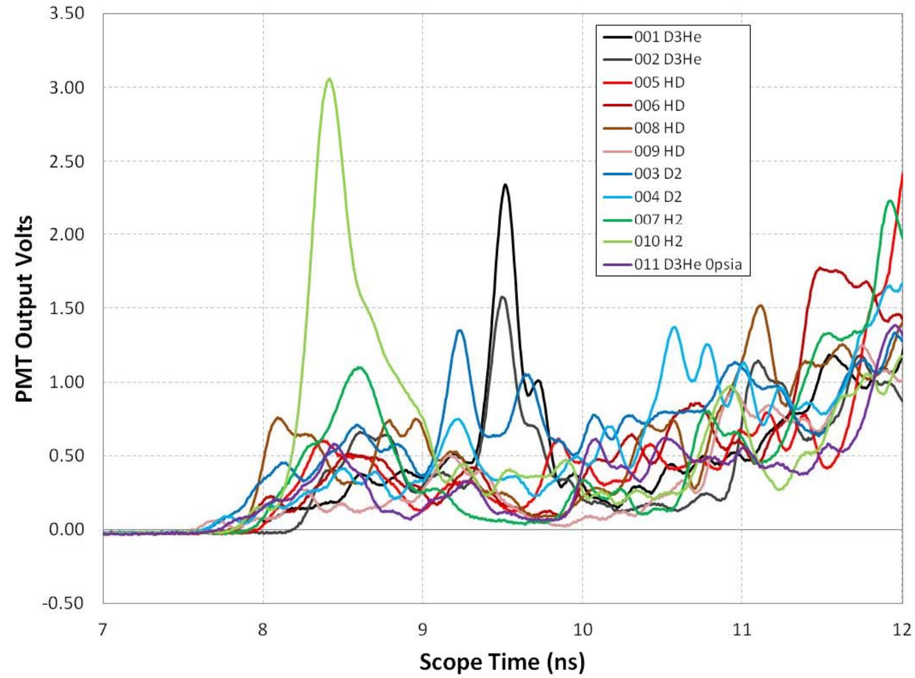
The new LANL GCD-3 will measure this γ ray for the first time in a HED plasma

GCD-3 provides clearer signatures of low-yield gammas than GCD-1

3 MeV (GCD-3)

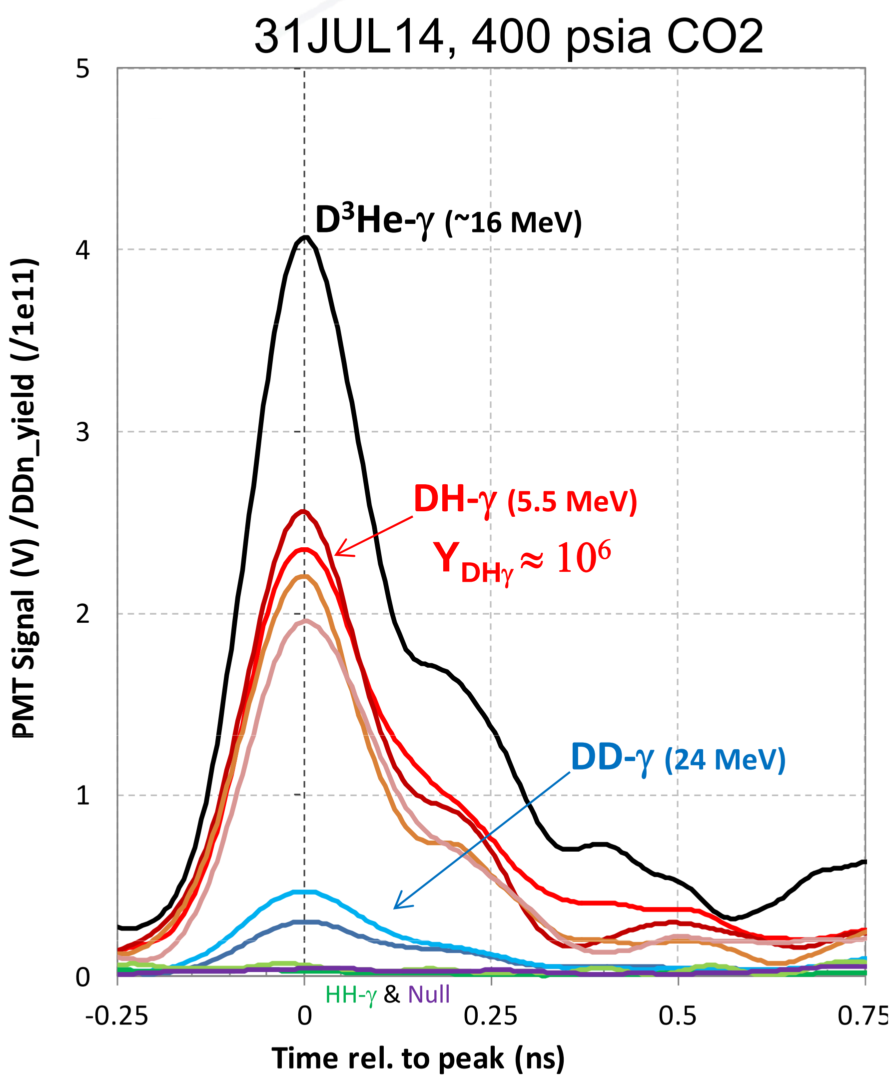


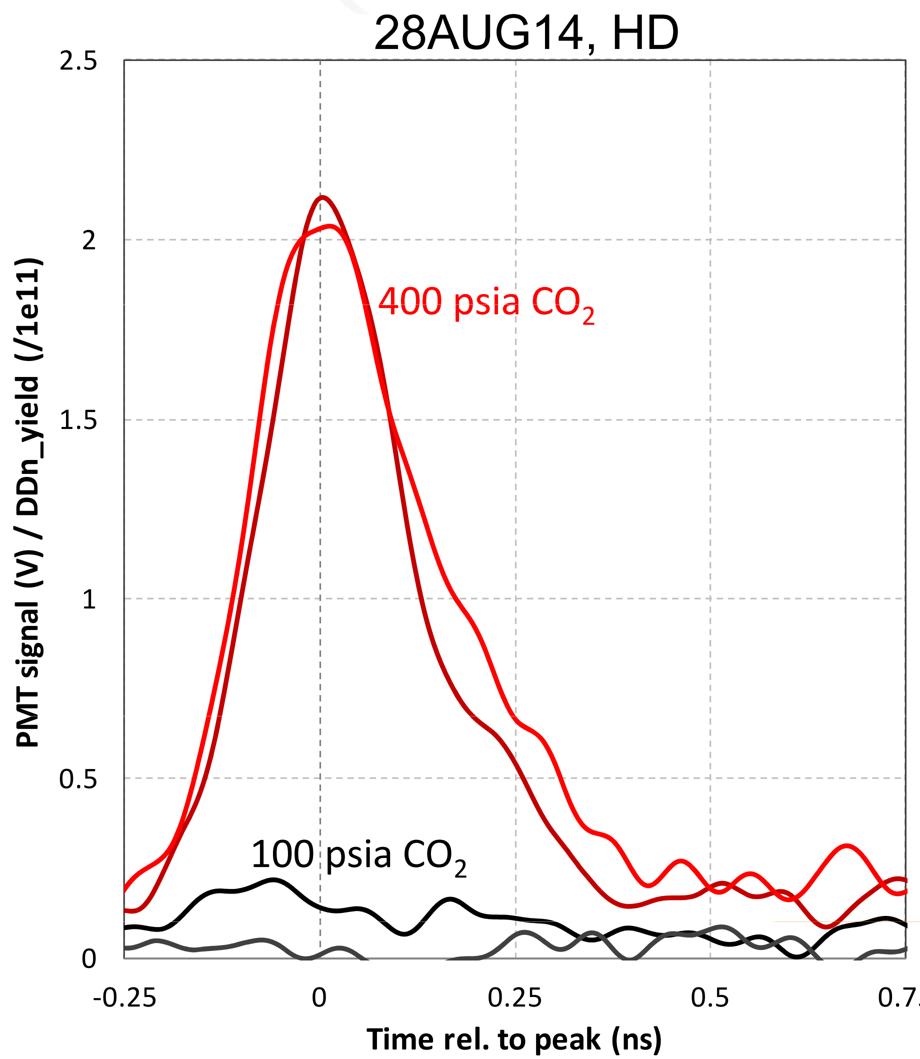
6.3 MeV (GCD-1)



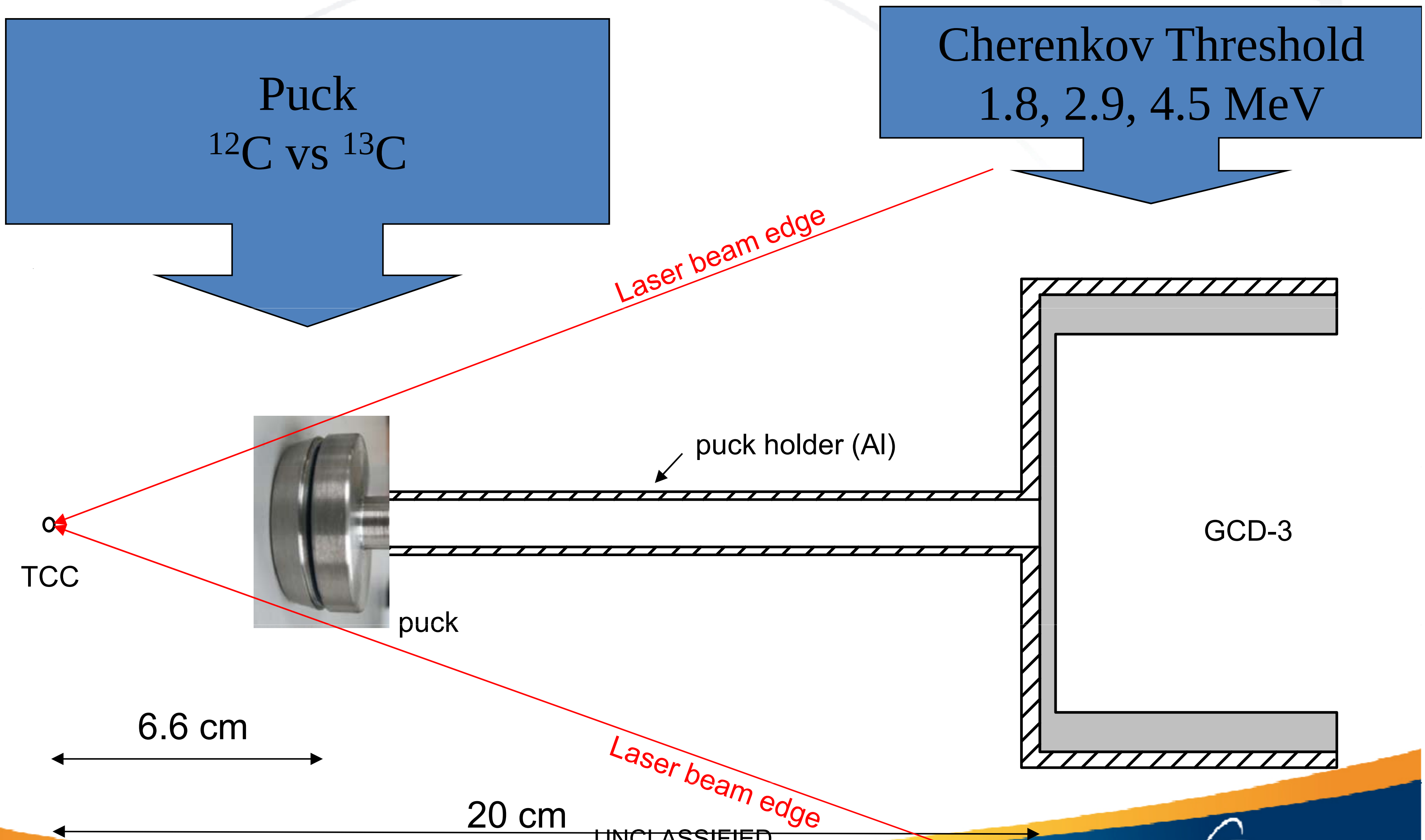
-As expected, no sign of 5.5 MeV DHγ on GCD-1 at 6.3 MeV threshold
-Possible hints of 24 MeV DDγ on GCD-1, but clear signal on GCD-3

GCD-3 has uniquely identified HD fusion gammas at 5.5 MeV and DD-γ at 24 MeV for the first time in July 2014

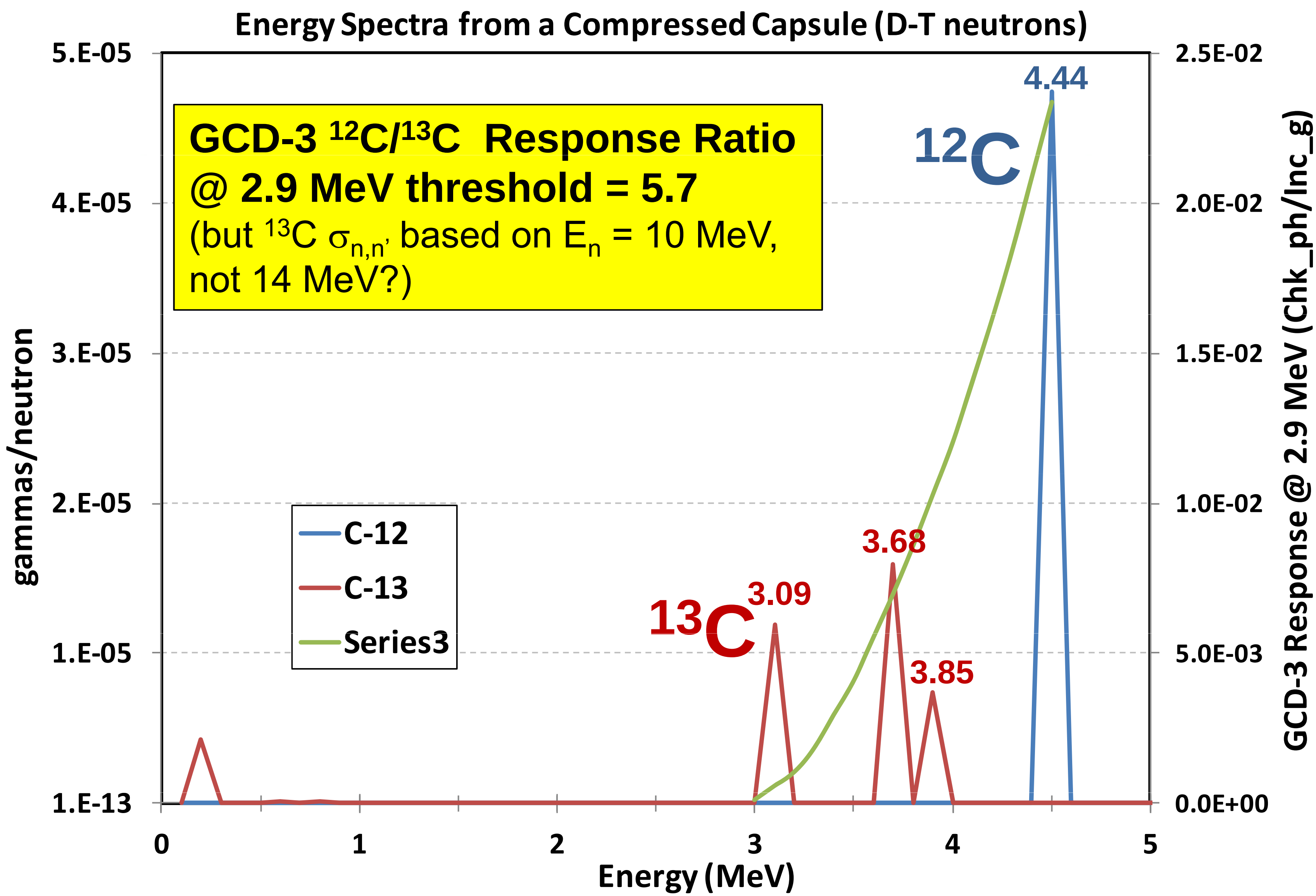




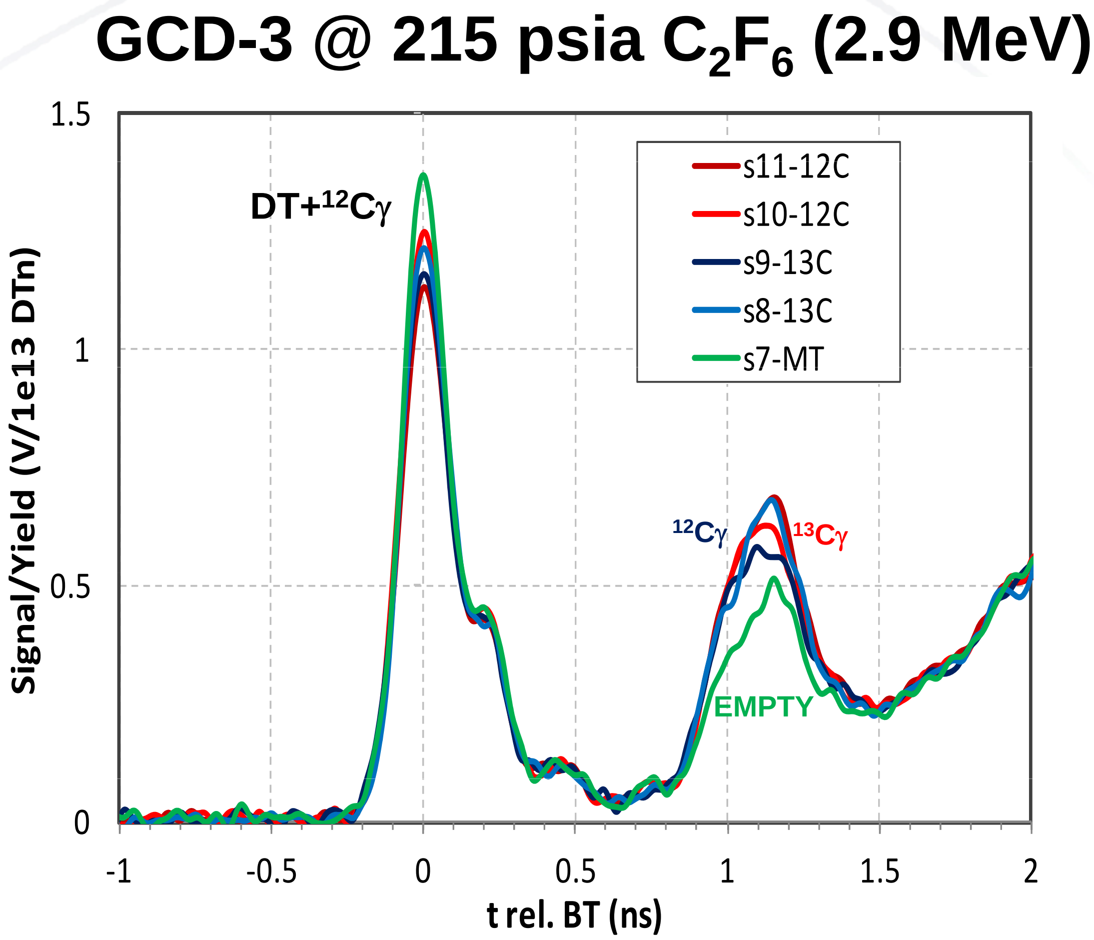
GCD-mounted powder-puck at Omega



GCD-3 Response



14 MeV (n,n') gamma emission from ^{12}C & ^{13}C powder pucks appear comparable



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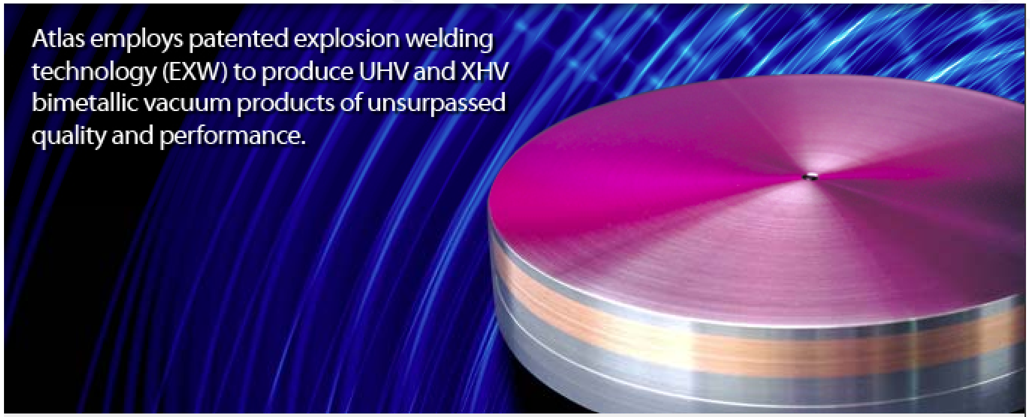
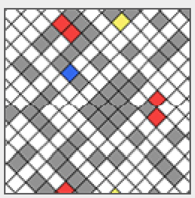
GCD3 had significant engineering challenges

- 400 psi C_2F_6 gas pressure
  - Required cell to be a certified ASME pressure vessel
  - Normally means a thick-wall stainless steel (SS) vessel
- Must weigh <100lbs due to TIM load capacity
  - Construction with SS would exceed weight limit
  - Aluminum is material of choice and rubber o-rings are typical
- Omega dictated that the leak rate shall be $< 1\times10^{-9}$ cc/sec at 1 atm He
  - Leak rate equates to 32 years for 1cc to leak out of vessel
  - Driven by concern of fluorinated gas contaminating chamber
  - Forced into crushed metal seals
  - Solution was explosion welded bi-metallic flanges (see next slide)
- High pressure window for PMT
  - Integral part of the pressure vessel
  - Required UV transmission & AR coatings
  - Glass to metal seal with low leak rate
  - Solution was brazed sapphire into SS flange (see slide after next)
- Internal optics package requires an integrated fiberoptic for calibration

Combination of light-weight and low-leak requirements led to Explosion Welded flanges



Explosion Welding (EXW) Technology



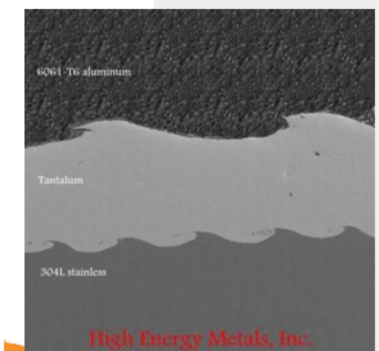
Click for larger image

Bimetallic Bonding for Ultrahigh Vacuum

Over the past 16 years Atlas Technologies has concentrated in developing methods and processes specifically intended for bonding dissimilar metals for use in Ultrahigh Vacuum (UHV). The details of this process are proprietary, but the following report provides a working understanding of the process. Atlas has received patents on several applications of this technology... including the metal-seal Atlas CF™ flange and Atlas ATCR™ fitting.

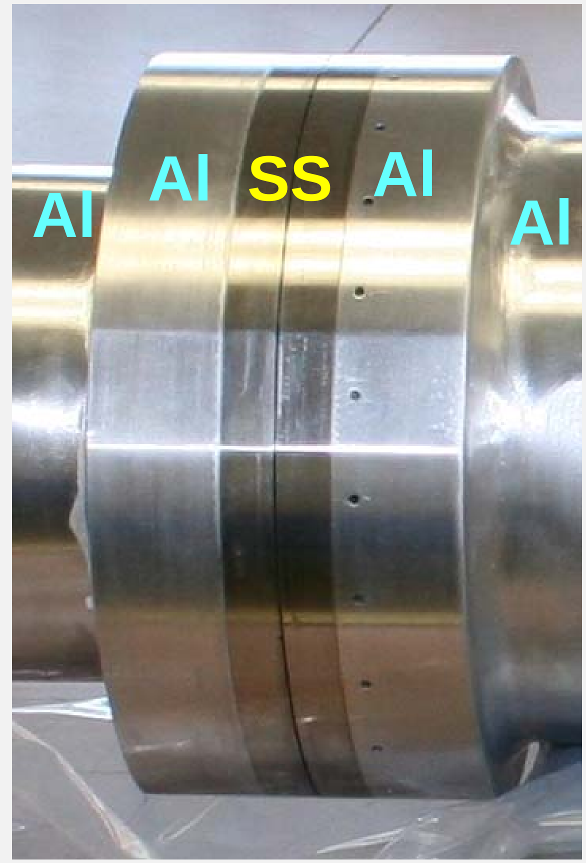
Metallurgical Bond

The Atlas CF™ flange is metallurgically bonded using an explosion welding process (EXW). Flange blanks are then cut from the bonded plate using a water-jet cutting process. Final machining of blanks assures UHV quality of the materials. Preparation for bonding requires that plates lay flat to each other. A flyer plate sits atop of a base plate and separated by a small gap. An explosive material, such as ammonium nitrate, is placed on top of the flyer plate and detonated from a point at one edge of the plate. The explosion is a controlled progressive ignition starting from one point on the surface of the flyer plate and progressing accross it, like the ripples on a pond created from the drop of a rock. The energy from the explosion accelerates the flyer plate against the base plate at impact velocities of 1800-2200 m/sec. A High energy surface plasma is formed between the plates, which moves ahead of the collision point striping electrons from the two bonding surfaces. The electron hungry metals are then thrust against each other at extreme pressures forming an electron sharing bond. Explosion welding (EXW) is a cold process that induces cold-work into the flyer plate, and a slight increase in magnetic properties when bonding to stainless steels. This effect can be mitigated if requested by the customer.



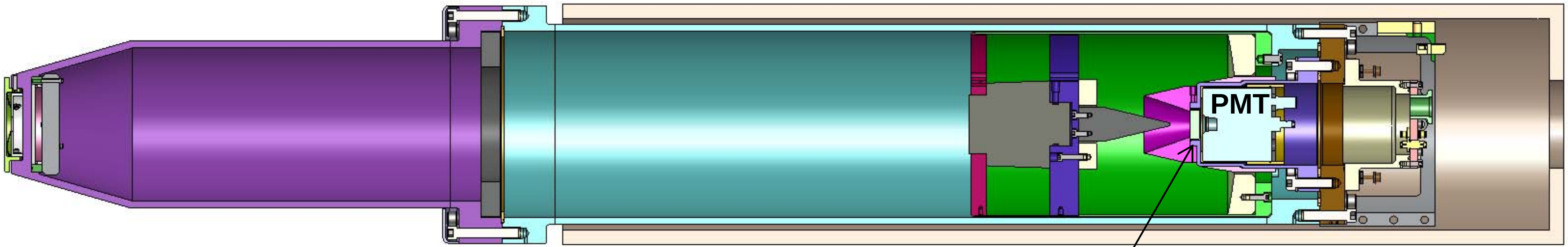
http://atlasuhv.com/#/technology/atlas-explosion-welding-exw-technology

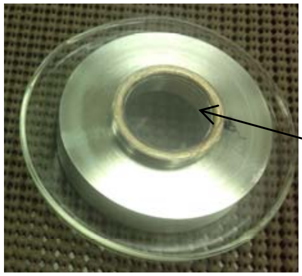
GCD-3 Bimetalic Flange



- Al for light-weight
- SS for low-leak knife edge

Brazed sapphire window proved challenging





Window flange

- First 2 attempts at welding SS window flange into PMT housing assembly resulted in cracked windows
- 2nd redesign to eliminate welding distortions near window

Enhanced performance GCD-3 is now operational on OMEGA, and acts as a prototype for a NIF GCD

- GCD-3 meets the requirements:
  - High pressure (≤400 psia) to provide Cherenkov threshold down to 1.8 MeV
  - Low leak rate (≤1e-9 scc/s at 1atm He) to prevent corrosion to tritium recovery system
- GCD-3 has now been successfully fielded on 3 OMEGA Shot Days (Jul/Aug '14)
  - Detected HD & DD fusion gammas for the first time in an ICF experiment!
  - Compared (n,n') gamma emission from 14 MeV neutron interaction with ^{12}C & ^{13}C "powder pucks" placed near DT implosions
- GCD-3 is performing as expected
  - Provides clean prompt gamma signal
  - Provides lower threshold capability than previous GCDs (1.8 vs 6.3 MeV)
  - Provides greater sensitivity than GRH (200x at NIF)

Backups

Category: Nuclear (n/γ) **1 page concept summary** *Diagnostic Workshop FY14*

Diagnostic: Super GCD (GCD-3 at OMEGA)

Diagnostic RI: H.W. Herrmann/W. Stoeffl
Responsible Org: LANL/LLNL/LLE
Which facility: OMEGA/NIF/Z?
Engineer: F. Lopez (LANL), A. Carpenter (LLNL)?

Purpose: Improved Gamma-ray history relative to GRH-6m:
1) ~200x Sensitivity
2) Threshold (1.8 MeV vs 2.9 MeV)
3) Temporal Response (~60 ps vs ~100 ps)

Primary experiment:
- Any DT w/ $Y_{DTn} \geq 4e11$* (e.g. CD/T2 MixCap); or D^3He w/ $Y_{D3Hep} \geq 2e11$*
  *100 detected gammas at 8 MeV threshold
- n-interactions with various “puck” mat’ls

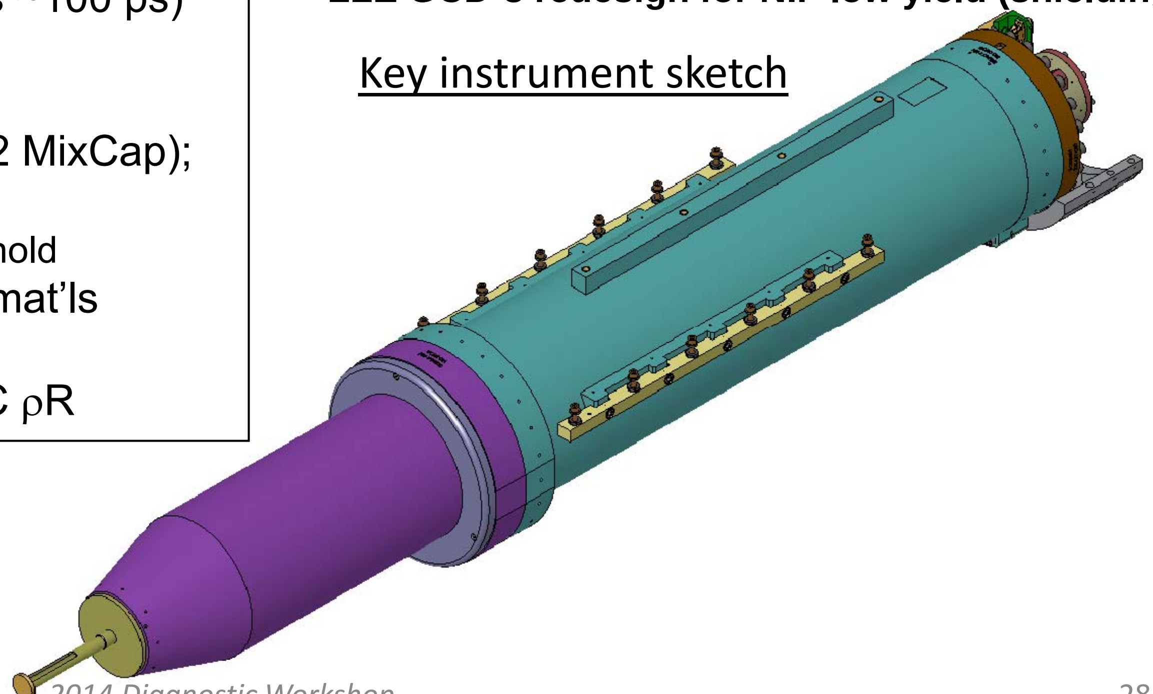
Primary data: Reaction History, ^{12}C ρR

Important description of the instrument:

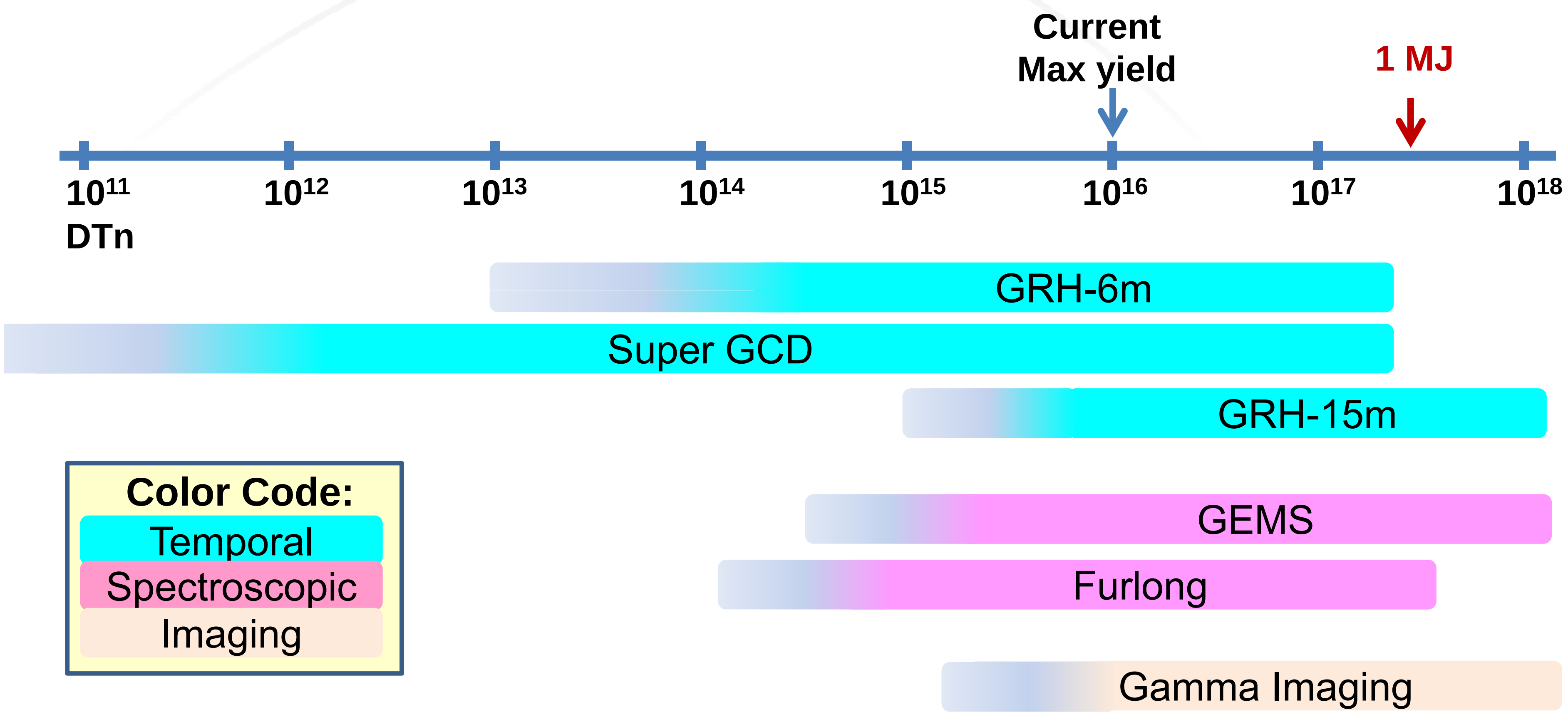
- **Key requirements**
  - **GBT & GBW to w/in 30 ps at Y_{DTn}>1e12**
- **Approximate NIF schedule ~1 yr ARO**
  - **~1yr for LLE version (high yield (>1e15), PD)**
  - **+~1yr for NIF version (low yield)**

Issues
- **LLE GCD-3 redesign for NIF low yield (shielding)**

Key instrument sketch



NIF Yield Ranges for Gamma Diagnostics



Increased sensitivity will allow use of fast photodiode (PD) at gain=1 for improved Reaction History at high yield (>1e15)

- Photek PD IRF yet to be accurately characterized,
  - expectation is <60 ps fwhm - see talk by J. Milnes next
  - as compared to ~100 ps fwhm PMT110
- Lowest GRH threshold cell (2.9 MeV) currently running PMT Gain ~30x
  - could switch to PD w/ high bandwidth amplifier, but requires intensive rigging operation & amp might introduce significant noise
- PD & MZ mounted directly on back of Super GCD (no amp needed)
  - "Gain" can be controlled by solid angle adjustment (i.e., standoff distance)

How it will be used on a key experiment and what kind of data it provides

Improved Reaction History as compared to GRH

- PD on LLE GCD-3 version at "high" yield (>1e15 DTn)

Provide Reaction History for previously undiagnosed experiments:

- CD/T_2 MixCaps with Yield > 4e11 DT-n
- D^3He SymCaps with Yield > 2e11 D^3He-p
- Likely requires redesign w/ lots of shielding against LPI x-rays

Provide neutron-interaction data (e.g., (n,n'γ), (n,γ))

- Global Security has expressed strong interest in "puck" studies

Category: **Nuclear (n/γ)**

Diagnostic status

GCD-3 Operational at OMEGA

NIF Requirements – TBD, but should be sufficient to hold a CDR soon

Additional required R & D and resources

- additional DIMs would help greatly!
- Conduit & Rack space

New technologies required – timeline and who's responsible?

- Fast Photodiode (Photek) available now

Engineering lead; outsourcing options

- LANL, w/ possible outsourcing to LLE, NSTec

Calibration needs – who is responsible?

- LANL responsible, see Calibration slide

Schedule – tied to a shot or other schedule requirements

- <1 yr to implement OMEGA GCD-3 on NIF
- Additional ~yr to optimize for NIF (i.e., more shielding)

Calibration needs

Cross-calibrations started at OMEGA in Aug 2014

- analysis underway

HIgS validation of GEANT4 detector models is important!

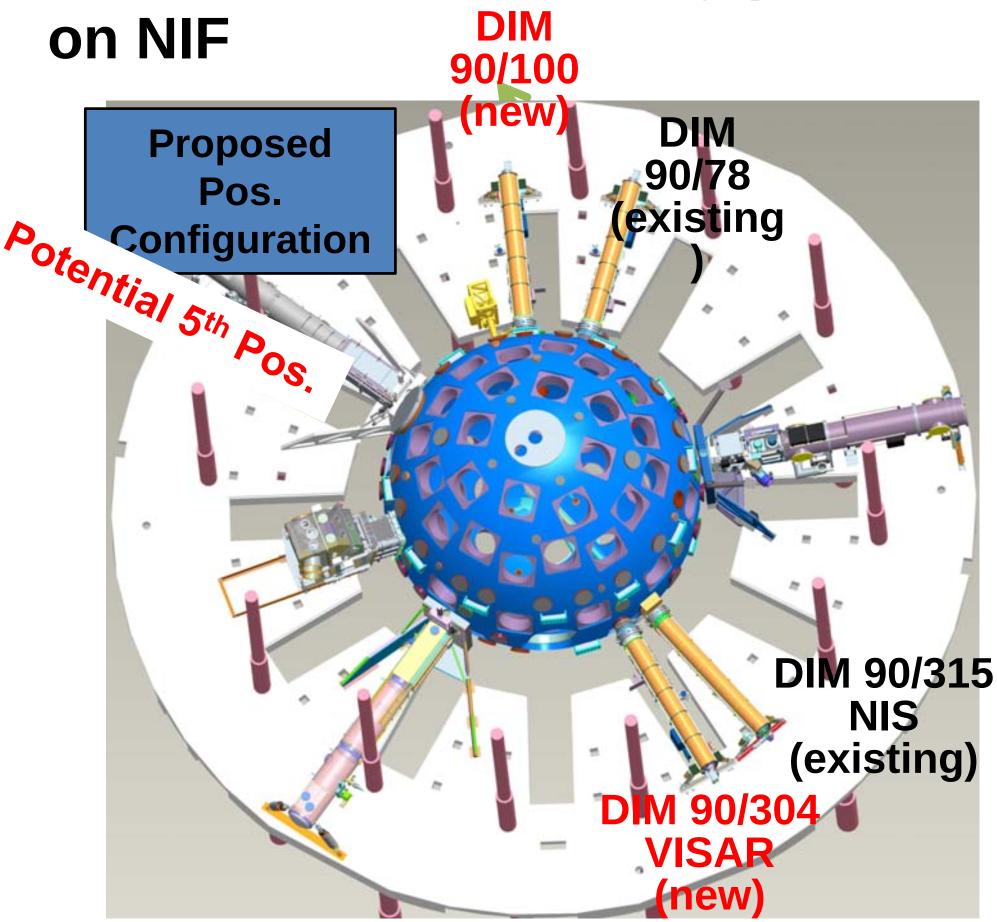
In-situ calibrations similar to GRH

- Exploding Pushers for yield cross-calibrations
- Carbon Puck for ρR cross-calibrations

PMT & PD characterizations needed, same as GRH

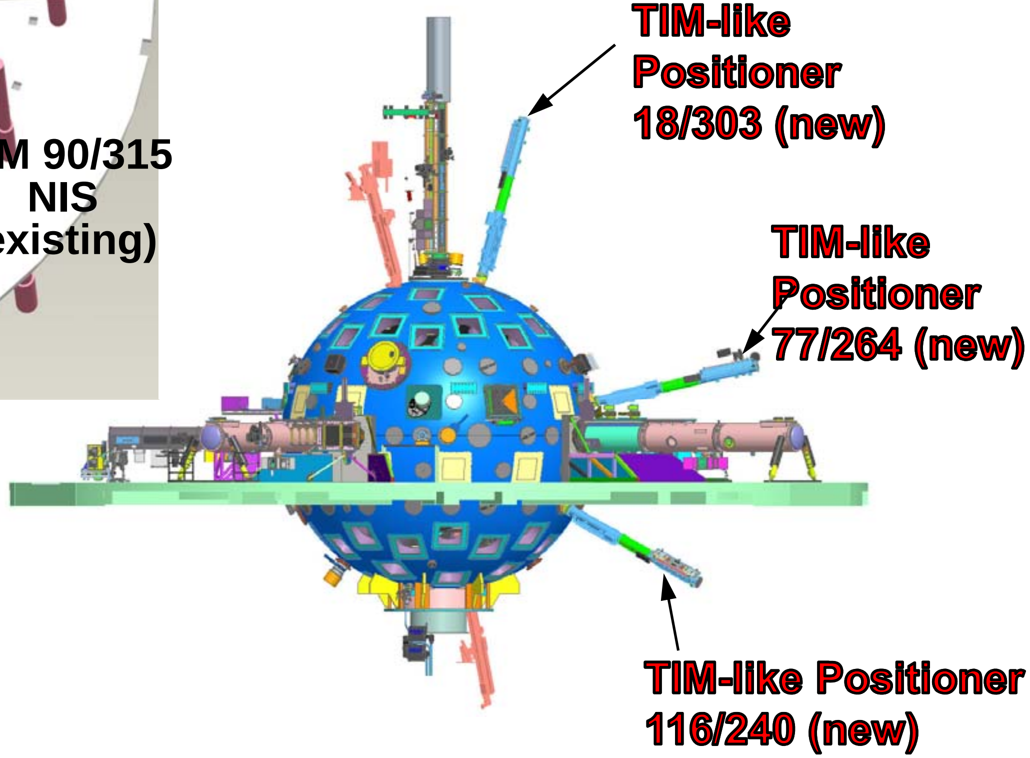
- Photek & NSTec/LO

Plans exist to eventually put more DIM & TIM positioners on NIF

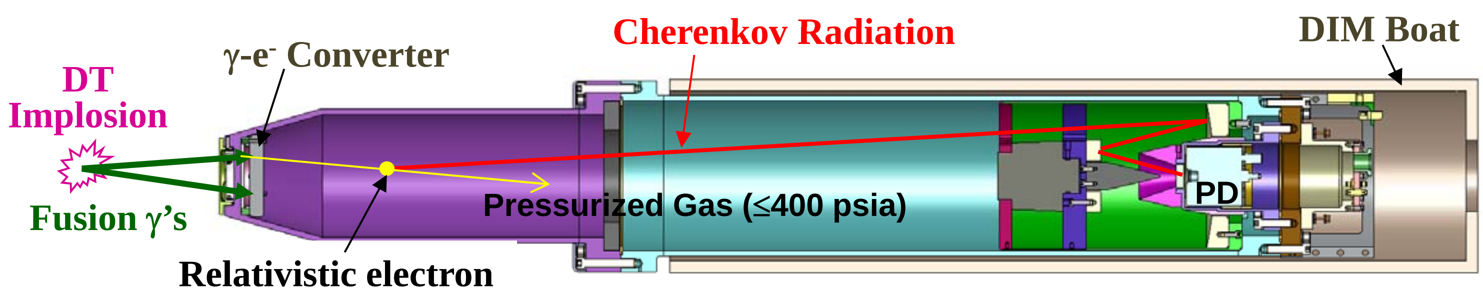


Perhaps as many as 6:

- 3 new DIMs
- 3 new TIMs



Doug Larson, May'12


DT
Implosion
γ-e⁻ Converter
Cherenkov Radiation
DIM Boat
Fusion γ's
Pressurized Gas (≤400 psia)
PD
Relativistic electron